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ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

DETONATING MUNITIONS DIVISION

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A.R.D.E. REPORT ~~(S) 4/56~~

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The Calorimetry of High Explosives

H. W. Sexton

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ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

A.R.D.E. REPORT (S) 4/56

The calorimetry of high explosives

H.W. Sexton (S.2)

Summary

A laboratory method evolved over a period of years is described for the determination of the heat and gases of detonation of up to 120 gramme charges of high explosives.

The report is divided into three parts:-

(1) The calorimetry of high explosives

(2) The examination of the products of detonation

(3) The evaluation of the heat and gases of detonation per gramme of charge.

The method is illustrated by results from the firings of four common explosives, i.e. Tetryl, Picric Acid, RDX/TNT 50/50 and TNT.

Approved for issue:

H.J. Poole, Deputy Director

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PART I. THE CALORIMETRY OF HIGH EXPLOSIVES

Introduction

Part I of this report describes the equipment and procedure which has been developed in this Establishment over a period of years for the measurement of the heat evolved when a charge of high explosive is detonated in a closed vessel. Other closed vessel work carried out in the Section comprises the measurement of heats of combustion and determination of the calorimetric values of propellants, the latter technique having been developed to a high order of accuracy.

The closed vessel or bomb used for the calorimetry of high explosives is of such size and strength as to permit charges of up to 120 gm. in weight being detonated in it. This entails the use of a vessel, which, together with its auxiliary apparatus of calorimeter, water-jacket etc. is much larger and heavier than the corresponding combustion or propellant equipment. The time occupied in carrying out a calorimetric measurement is also much longer. For example, the bomb itself weighs about $5\frac{1}{2}$ cwt. and temperature readings are continued in the course of a single experiment for 7 to 8 hours.

The equipment is housed in a reinforced concrete structure and firing is carried out electrically by remote control. If a vessel fractures on firing some damage to the equipment is unavoidable, but the production of dangerous missiles from the bomb casing is not a likely contingency. The closing lids of the calorimeter and water jacket will be ejected violently and the water, mixed with soot, will be thrown out. As the products of detonation contain toxic gases, especially carbon monoxide, good ventilation has to be provided to ensure their rapid dispersal.

A. The Closed Vessel

1. Material

The earliest type of bomb, first used in 1921 was made from a nickel-chrome steel of the following composition:-

Carbon	0.69 per cent
Nickel	2.97
Chromium	2.31
Manganese	0.09
Sulphur	0.10
Phosphorus	0.029

About 150 charges were fired in it, many of them of 120 to 130 grams. weight. At the end of its life its sides had bulged but not fractured and its inner surface had become badly scored with the loss of 1500 c.c. of steel. Such good serviceability is no doubt largely due to the heat treatment of the steel.

Systematic work on the calorimetry of high explosives then lapsed for a number of years, to be resumed in 1942. An attempt was made to copy the original vessel, but unfortunately details of its heat treatment were no longer available. A Vibrac steel was adopted made by the English Steel Corporation to specification B.S.S. En.26-V.12 (treated condition T.2).

Vessels of this material, however, fractured after a few firings with the largest charges, the cause being traced to the difficulty in obtaining a homogeneous heat treatment of forgings of the shape and size of the vessel. More recently, several vessels have been satisfactorily heat treated and these have proved capable of taking charges of 120 to 130 grams.

The bomb is shown in dimensional detail in Fig. 1. It has a plain cylindrical body 24 in. high and 12 in. in diameter, with a wall thickness of $2\frac{3}{4}$".

2. <u>The Method of Sealing</u> Fig. 1 Parts 4 to 8

It is of course essential that all joints in the bomb should be at least as strong as the material itself in withstanding without leakage the intense detonation pressure. The method of obturation to be described is the product of much practical experience.

On the inner surface of the head of the bomb is a circular groove which corresponds with a projection of hemispherical cross section on the top of the body. The groove is initially filled with solder. When the head of the vessel is tightened against the body, the solder spreads and is partially extruded out of the groove. This forms an initial seal to the vessel and enables it to be evacuated of air and filled with an inert gas (nitrogen or argon) as required.

The main seal comes into operation when the charge is fired. It consists of a steel baffle plate from which the charge is suspended, a knife ring and lead washers. When the charge is detonated the pressure of the gaseous products is transmitted by the baffle plate to the knife ring which is designed to force the lead into any gaps formed at the joint and so ensure that the gases are retained. It is found convenient to make the lead washer in two parts; the knife ring and lower washer can then be used for at least two firings and only the upper one need be removed and replaced each time. The knife ring is of good quality steel and the lead washers are turned from rolled lead sheets made from Broken Hill lead alloyed with 0.3 per cent of tin.

3. <u>The Baffle Plate</u> Fig.1 Parts 6, 7 & 8

This is a flat plate of steel made up of a central disc and two concentric rings screwed together. The confining vessel containing the explosive charge with its booster and detonator is suspended from the disc by means of two steel rods $\frac{1}{8}$ in. diameter and 6 in. long bolted to the disc. The detonator leads also pass through the disc. The inner ring is of such a diameter that, after a firing with a new knife ring, it can be removed in one piece with the disc, leaving the outer ring, knife ring and lower lead washer undisturbed for further use.

4. <u>The Electrode</u> Fig.1 Parts 9 to 17

The design of this component is common to all the equipment used in the Calorimetric Section. The unit is complete in itself and is sealed into the head of the bomb by means of a copper washer. It consists of a stem of mild steel insulated from the body by means of an ebonite tube and kept in position by two tufnol washers. The inner end of the stem is enlarged in diameter, with a gap between it and the body which is filled with a fire-proof cement. In practice, providing the free surface of the cement is repaired when occasion arises, the electrode should last for the life-time of the vessel without replacement.

5. The Outlet Valve Fig. 1 Parts 18 to 22

This valve is of a modified 'cone' type. It is to be noted that the seating is countersunk conically and that the cone fits loosely into the spindle, thus being free to adjust its line of centre to that of the seating. The cone is made of mild steel so that such permanent distortion as takes place is divided unequally between the hard seating and the softer cone, the latter being the easier to replace.

6. The Confining Vessel Fig. 1 Part 10 Fig. 3

The confining vessel which houses the explosive charge is made from mild steel tubing. The detonator is held in position by a steel holder and projects to the base of the exploder pellet as indicated. The charge is either in the form of pre-pressed pellets or is cast directly into the vessel.

B. The Auxiliary Calorimetric Equipment

1. The Calorimeter Fig. 2 Part 1

The calorimeter was originally made of copper reinforced with steel bands. It was found, however, that the shock waves transmitted through the vessel caused distortion and finally fracture of the bands. The present design is in form of a steel tube of $\frac{3}{8}$ in. wall thickness with a 1 in. thick base welded on. Three steel strengthening bands 6 in. wide and $\frac{3}{4}$ in. thick are welded round the middle of the outer wall of the calorimeter.

During an experiment the calorimeter contains the closed vessel and 26,000 ccs. of water and is closed by means of a copper lid. On firing, the water is thrown into a state of violent turbulence, and it is therefore important that the lid should be sufficiently tight-fitting to prevent any appreciable quantity of water being ejected into the space between the vessel and its water jacket.

A method of stirring by continuous flow is employed, by which the water is raised by the rotation of propeller blades in an external housing and shot tangentially into the top of the cylinder in which the closed vessel is placed. The speed of rotation of the blades is 500 revs./min.

2. The Water Jacket Fig. 2 Part 27

The calorimeter stands inside a water jacket or tank on a heat-insulating platform made of ebonite with four short legs of the same material. There is an air gap about two inches wide between the inner wall of the jacket and the outer wall of the calorimeter. A simple propeller-type stirrer rotating at 100 revs./min. is employed to maintain the water in the jacket in circulation.

The jacket is lagged on the outside with thick felt in order to insulate it as far as possible from the losses of heat to the atmosphere. In practice, however, the effects of the room temperature on that of the tank are found to be appreciable owing to the length of time needed to complete a trial. In order to compensate for them, a 100-watt lamp connected to a rheostat is partially submerged in the tank as well as a water-cooled coil. By means of these it is possible to maintain a steady temperature in the tank throughout the experiment to within $\pm$ 0.050° C.

The water jacket has a well-fitting light wooden lid with supports to which the thermometers used to measure the temperature rise in the calorimeter can be clamped.

3. The Thermometers

Mercury-in-glass thermometers are used to record the temperature changes in the calorimeter. They are nitrogen-filled and are graduated in hundredths of a degree C. in the range 12 to 24 degrees. By means of a magnifying eyepiece they can be read to 1/1000 th. of a degree. The probable error of calibration is not more than $\pm$ 2/1000 ths. of a degree. The rise in temperature in the calorimeter being usually about 2 degrees. This order of precision of the thermometers is in excess of the overall accuracy of the experiment which cannot be considered to be better than one per cent.

C. Details of the Experimental Procedure

1. Assembly of the Confining Vessel Fig.3

The charge is loaded into the confining vessel in cast or pelletted form according to the nature of the explosive under test, followed by the exploder. The latter is in two parts (a) a pressed pellet $\frac{1}{2}$" long, which rests on the main charge, followed by (b) a pellet $\frac{1}{4}$" long perforated to accommodate the detonator, usually No.8 A.S.A. electric in an aluminium sheath.

As a confining vessel of standard length is employed, any empty space below the main charge is filled up with a steel plug, and the end cap screwed on. The detonator, in its holder, is slid into position and held in place by the top screwed cap, through which the detonator leads are passed. The two supporting rods are then assembled and their free ends secured to the centre disc of the baffle plate with nuts. The leads are threaded through the hole provided for the purpose.

2. Assembly of the Closed Vessel and Calorimeter System

The bomb is strapped to the walls of the laboratory with steel hoops and the head of the vessel, its circular groove having been previously filled with solder, is suspended by means of block and tackle over the open end. The two outer rings of the baffle plate, the knife ring and the lead sealing washers are assembled and the centre disc with confining vessel attached is screwed into position and the detonator leads connected to the terminals, on the inside of the head. When the head has been slowly lowered into position, the twelve studs are tightened down in pairs diagonally across the bomb so that the head is evenly stressed. The tightening is repeated after an interval of 2 to 3 hours, and again after leaving the bomb overnight.

The tank temperature is first adjusted to 20.5°C and the room to 20.8°C. The closed vessel is evacuated to a pressure of not more than 2 mm. of mercury and charged with nitrogen to a pressure of between 50 and 100 mm. above atmospheric; the pressure is carefully measured. The excess pressure is a precaution against water being drawn into the vessel in case it is not absolutely gas-tight. When the bomb has been lowered into the calorimeter and the firing leads connected up a volume of 26 litres of cold water is introduced from graduated vessels. The stirrer is run for about 20 mins. After 20 litres have been added, the remaining 6 litres are then used to adjust the initial temperature to the desired value. This is so chosen that the final temperature in the calorimeter is at least $\frac{1}{2}$°C and not more than $\frac{3}{4}$°C above the steady tank temperature. Under these conditions a rising temperature in the calorimeter is ensured throughout, thus reducing errors due to stiction in the thermometers. The reasons for the choice of the temperatures of tank, calorimeter and room are discussed in the next paragraph. When the temperatures have been adjusted the covers are placed in position and the apparatus is allowed to stand for atleast three-quarters of an hour.

3. Temperatures of Tank Calorimeter and Room

In selecting the initial calorimeter temperature and the steady temperatures of the tank and room it is necessary to consider the mode of heat transfer in the system as a whole.

Figure 4 gives a typical time-temperature curve for the calorimeter during an experiment. AB and CD represent the steady temperature rises before and after firing, whilst BGC covers the heating period, after firing, when the heat of detonation is being transmitted through the walls of the closed vessel to the calorimeter and contents.

During steady temperature rises in an ideal system, the difference in temperature between the tank and calorimeter, should alone control the rate of rise in the calorimeter, heat being transferred across the air gap between them, by conduction and radiation and to a minor extent by convection. Figure 5 line 1 indicates the relationship which should exist between these factors of temperature rise.

In the apparatus, being described in this report, the ideal system is not attained. The main imperfections being that:-

(a) The air gap between the tank and calorimeter is at least 4 cms. instead of 1 cm. as recommended for standard equipment. It is unfortunate that this gap cannot be reduced but provision has to be made in the design, for the movement of the calorimeter on firing due to the effects of the detonation and for the re-inforcing bands which project from the walls of the calorimeter.

The effect of the wider air gap, is to increase the proportion of heat transferred by convection. The pattern of these free convection currents are affected at the top of the system, by the room temperature. The main effect of room temperature could be removed, of course, by insulating and hermetically sealing the lid into the tank. In event of a 'blowout' at the valve or electrode, with the resulting increase in pressure, such a closed system would be ruined, whilst as it is designed at present the light wooden lids to the tank would be blown off without serious damage to the rest of the tank equipment.

(b) The temperature measurements of the water in the tank and calorimeter do not indicate accurately the true temperature of their outside walls at any given time. This is due partly to the difficulty in obtaining a stirring system capable of removing all temperature gradients in an apparatus of the size under consideration and also to the thickness of the walls of the calorimeter.

(c) Thermal leakages into the system occur; e.g. between base of calorimeter and tank.

(d) Heat is generated by the stirring.

Some of the effects of poor stirring can be nullified by placing the thermometers in the same position and at the same depth for all experiments including those from which the water equivalents of the system are determined. However, the remaining imperfections are such that a plot of the rate of rise in the calorimeter against the difference in temperature between tank and calorimeter as shown in Figure 5 line 2, is entirely different from that expected from an ideal system.

The method of computation of net temperature rise discussed later in Section D applies providing a linear law of heating is applicable. It will be seen in Figure 5 that this is only the case over the range of tank-calorimeter temperatures -0.75 to + 2.75°C and in consequence the initial temperatures of tank and calorimeter have to be chosen so that throughout the experiment the measurements are covered by this range of temperatures.

Fig.5 also indicates that the proportion of the rate of rise in the calorimeter due to causes independent of the tank and calorimeter temperatures, is large in comparison with that due to the influence of the tank temperature. The magnitude of this effect is indicated by the rate of rise in the system at zero Tank - calorimeter temperature. However providing this effect can be kept constant throughout the experiment it will not affect the computation of the net temperature rise. (See Part 1 Section D).

This is done by standardisation of all factors on which the rise in temperature in the calorimeter depend, i.e. rate of stirring, position of closed vessel in the calorimeter and calorimeter in tank and the temperatures of various parts of the system.

Therefore the tank temperature is always fixed at 20.5°C, and the initial temperature of the calorimeter is chosen so that the final steady rise in the calorimeter will take place between temperatures 21° and 21.25°C. Under these conditions the rise of temperature in the calorimeter will be very slow during the after firing period, but this will be an advantage in determining the time when the final steady period commences.

The room temperature is kept as constant as possible at 20.8 which corresponds to the mean temperature of the air gap during the long final steady rise in the calorimeter.

4. Temperature Readings

Readings are taken on two thermometers. These are first placed in iced water for a few minutes to bring them to a standard state and then clamped in position in the calorimeter to a standard degree of immersion for reasons stated in Section C.3. Readings of the pre-firing temperature range are made on each instrument alternately at half-minute intervals for about 45 minutes, the thermometers being tapped before reading. They are then removed from the room and the charge is fired by remote control.

The thermometers are then chilled again and replaced at the temperature at which they were removed. Readings are started again immediately and continued at half-minute intervals on each thermometer for about an hour after which they are reduced to once every five minutes to the end of the experiment, usually for 4 or 5 hours. The temperatures of the water jacket and room are read every 5 minutes throughout the experiment, the water jacket being maintained at its initial temperature by means of heating lamp or water cooled coil.

D. Computation of the Net Temperature Rise

Figure 4 shows a typical temperature-time curve for an H.E. firing. ABGCD represents the temperature of the calorimeter during a determination, the charge being fired at time t_2. Over very small ranges of temperature difference such as occur between the calorimeter, the tank and the surrounding air, a linear law of heating represents the effects appropriately, as indicated in C.(3) above. The amount of radiant heat that is added to the system in time δt may be taken as $K(\theta_5 - \theta)\ \delta t$, where θ is the variable temperature of the system and θ_5 is a steady temperature defined by the temperature of the tank and of the surrounding air. To this must be added a term $A\ \delta t$ where A is the uniform rate at which heat is generated by the stirring, or other similar causes.

The quantity of heat which passes into the system from outside between times t_1 and t_5 is thus given by the expression

$$K \int_{t_1}^{t_5} (\theta_5 - \theta)\, dt$$

where θ passes along the line ABGCD, that is to say, it is proportional to the area ABGCDNHA.

In practice AB and CD are straight lines, and the determination of their slope is an important feature of the measurements. When the curve has been plotted a line FE is chosen such that the areas BEG and GFC are equal. The amount of heat passing into the system from outside is thus proportional to the sum of the areas AHLE and FLND. The portion of the total temperature rise which is due to heat generated within the closed vessel is necessarily independent of the exact times t_1 and t_5 at which the measurements are begun and finished. Points A and D may therefore be moved to any positions on the lines ABE and DCF without altering the value of the computed rise. When they are thus moved to the positions E and F the radiation effects (areas AHLE and FLND) become zero. EF is therefore the computed rise.

The rate at which heat is generated by stirring etc. is kept steady throughout an experiment and its effects on the measured temperature rise may be expressed as $A(t'' - t')$ where t' and t'' are the times corresponding to the initial and final temperatures respectively. In the process discussed in the preceding paragraph $t' = t'' = t_3$, so that $A(t'' - t')$ is zero; by this process, therefore, the effect of constant heating is automatically eliminated.

E. Determination of the Water Equivalent

In the course of closed vessel work with propellants the water equivalents of special vessels of stainless steel, which are used with systems much smaller than the HE equipment, are standardised by the combustion of standard samples of benzoic acid (supplied by the U.S. Bureau of Standards) and salicylic acid and using the accepted heats of combustion of these materials. The calorimetric values of carefully prepared samples of propellants are then determined in terms of these water equivalents. The standardised propellants are then used in the calibration of new equipment, and Table 1 below gives the results of three recent water equivalent determinations of an HE assembly obtained in this way.

Table 1

1 Weight of Charge Gm.	2 Theoretical heat at 957 cal/gm. Cal.	3 Correction for initial air in vessel and igniter Cal.	4 Correction for CH_4 and NH_3, formed Cal.	5 Total Corrections Cal.	6 Theoretical heat corrected Cal.	7 Measured rise °C.	8 Water Equiv. Gm.
140	133980	12285	363	12648	146630	1.996	73460
140	133980	12285	363	12648	146630	1.996	73460
289	276573	12160	290	12450	289025	3.952	73140

The exact agreement between the first two experiments is of course fortuitous, but it is estimated that the accuracy of the results does not exceed 0.5 per cent.

Experience shows that, apart from any deliberate alterations in the thermal capacity of the system, the water equivalent changes little as the result of repeated firings. Some loss of steel from the internal walls of the bomb due to scoring and erosion is inevitable, but this can be allowed for, if appreciable, when the capacity of the bomb is measured. It is considered to be a wise precaution, however, to carry out a check test of the water equivalent after, say, 50 firings.

PART II. THE EXAMINATION OF THE PRODUCTS OF DETONATION

Introduction

Part II of this report describes the procedure after the calorimetry has been completed. It deals with the measurement of the volume of the gaseous products and the collection of samples for analysis, and gives a general outline of the methods of analysis employed.

A. Measurement of Gas Volume and Collection and Sampling of Products

The volume of gas at N.T.P. produced by the detonation of a high explosive is usually of the order of 1 litre per gram. Suitable measuring vessels are provided by two calibrated porcelain carboys of 110 litres capacity. They are well protected from draughts and maintained at a fairly steady temperature.

To measure the gas volume the bomb is removed from the calorimeter and connected to the carboys and a mercury manometer via the two-way tap of a gas sampler. In addition three bottles of measured capacity (about 1 litre each) are connected to side arms to enable gas samples to be taken from the carboys at the end of the experiment; these are used for the volumetric analysis of the bye-products ammonia, hydrocyanic acid and cyanogen. The carboys and bottles are evacuated to a measured pressure of about 2 mm. Hg and the gas sampler is filled with mercury. With the connections to the sampler and bottles closed, gas from the bomb is allowed to flow into the carboys at such a rate that the pressure rises to half its final value of about 50 cm. Hg. in one minute. When the pressure in the carboys has risen to 25 cm. of Hg. the flow of gas is diverted into the sampler, in which approximately 250 ml. is collected. By the aid of mercury reservoir attached to the sampler the final pressure in it is built up to a pressure of 100 cms. of Hg. This prevents any leak into the sampler. At the end of the experiment the actual volume of gas at N.T.P. collected in this way is measured. The rest of the gas is then allowed to flow into the carboys, and pressures and temperatures are read until steady values are obtained.

From this data, the total volume of gaseous products, corrected to N.T.P. can be calculated as distributed between the bomb, the carboys and the sampler. The bottle samples are taken by closing the valve on the bomb and allowing gas to flow into them from the carboys, pressure and temperature being noted. Each bottle contains about 1 litre of gas at a pressure of approximately 50 cm. Hg.

After the gas has been withdrawn as described above, the closed vessel has a negative pressure. This enables 250 ml. of water to be drawn in through the valve. The head and baffles are then removed and deposits of soot etc. are washed into the bomb. The walls are also thoroughly washed down and all water and solid particles are sucked out and large fragments removed by hand. Recognisable remains of the confining vessel are rinsed, dried and inspected as a criterion of a satisfactory order of detonation. The residue of soot, steel particles etc. is filtered from the wash-water, dried and added to the vessel fragments. It is convenient to store the solid residue in two portions which pass and do not pass a 30-mesh sieve respectively, in case the finer particles are required for analysis.

This method of gas sampling and volume determination has to be modified if a gravimetric determination of the water of detonation is required. (See Section D2).

B. Analysis of the Gaseous Products

The analysis of the gaseous products of detonation is carried out by methods evolved by Dr. H.R. Ambler, formerly of this Establishment. They will be found in detail in "Technical Gas Analysis" by Lunge and Ambler, published by Gurney and Jackson. The analysis is done in two stages

(a) for methane and nitrogen by partial combustion methods,

(b) for acid gases (principally carbon dioxide, but including any hydrogen cyanide and cyanogen), carbon monoxide and hydrogen by absorption and combustion methods.

1. Methane and nitrogen

A measured quantity of gas of about 40 ml. is expanded under reduced pressure and slowly passed through a furnace tube at 295°C., packed with asbestos impregnated with copper oxide and backed with soda-lime and calcium chloride. This operation effects the oxidation and/or absorption of all gases with the exception of methane and nitrogen. The volume of these residual gases is measured and they are then transferred to another apparatus and combusted with air by means of a hot wire maintained at bright yellow heat. From the resulting contraction due to methane burning to carbon dioxide and water the percentages of methane and nitrogen in the original sample are determined.

2. Acid gases, carbon monoxide and hydrogen

These gases are determined on a further sample of about 15 ml. The acid gases are absorbed in potassium hydroxide and the carbon monoxide in ammoniacal cuprous chloride. The bulk of the hydrogen is removed by sparking with excess of air and the remainder by burning with a hot wire at bright yellow heat. The methane will also burn with the hydrogen and it is therefore necessary to remove and measure the resulting carbon dioxide after combustion. From the various gravimetric and volumetric measurements the percentages of the constituent gases can be calculated. The residue is taken to be nitrogen.

Since the true volume of the nitrogen in the gases is of importance in the treatment of the final results, especially if there is a possibility of metallic nitrides being formed in appreciable quantity, it is desirable to check the value arrived at by difference as described above. The sum of the percentages of methane and nitrogen from stage (1) and of acid gases, Carbon monoxide and hydrogen from stage (2) should total 100.0, and in practice this figure does not normally vary by more than 0.2. If a wider difference is found the analysis is repeated.

C. Volumetric Analysis

1. Ammonia, hydrogen cyanide and cyanogen in gaseous phase

(a) Ammonia is estimated by absorbing the gas in one of the bottles referred to above in 25 ml. of standardised, approximately 0.1 N sulphuric acid and titrating with approximately 0.1 N caustic potash solution, using bromophenol blue as indicator. The caustic potash solution is previously standardised against the acid.

(b) Hydrogen cyanide and cyanogen are estimated in combination by absorbing the gas in the second bottle in 0.1 N caustic potash and titrating with standardised 0.01 N silver nitrate. The indicator used is a solution of potassium iodide.

(c) In the third bottle hydrogen cyanide alone is absorbed in 25 ml. of 0.01 N silver nitrate solution previously acidified with a little dilute nitric acid. This is back titrated against approximately 0.01 N ammonium thiocyanate, previously standardised, using as indicator a solution of ferric alum. As a check on the volumetric result, the precipitate of silver cyanide may be filtered, dried and weighed.

2. Products in solution

The volume of the wash-water from the bomb, usually amounting to between 800 and 1000 ml., is measured. It may contain ammonium bicarbonate, ammonium cyanide and hydrogen cyanide.

Total ammonia present can be determined in two ways, (1) by titrating 25 ml. portions of the solution with standard 0.1 N sulphuric acid or (2) by distilling 100 ml. portions of the solution with caustic soda solution, collecting the ammonia gas evolved in standard 0.1 N sulphuric acid and back titrating against caustic potash of known strength. Total hydrogen cyanide plus cyanogen is estimated by adding 25 ml. of the solution to 25 ml. of 0.1 N caustic potash solution and titrating with silver nitrate as in (1) (b) above. Similarly total hydrogen cyanide is estimated as in (1) (c) and total cyanogen found by difference.

The ammonia determined in solution is taken as being present as ammonium bicarbonate.

D. The Water Content of the Final Products

1. Theoretical estimation

When the products have been analysed, the amount of oxygen thus accounted for is compared with that known to have been present in the charge and booster before firing. With charges consisting of orthodox non-metallised explosives the hydrogen and oxygen content of the final gaseous and solid products is invariably in default of that introduced originally. Owing to the reducing nature of the final gases it is assumed that the "missing" oxygen can only have formed water, the quantity of which is estimated accordingly. The "missing" hydrogen can also be taken as having formed water and affords a further method of its estimation. Therefore a mean of both values is taken.

2. Quantitative Estimation of Water

The water present in the final products is of course, condensed in the closed vessel. In order to measure it quantitatively, a weighed glass spiral immersed in a freezing mixture and backed by tubes containing phosphorus pentoxide, is inserted between the bomb and the sampler during the collection and measurement of the gases as outlined in Part II para. A. The increase in the weight of the spiral and backing tubes during the experiment is taken to be due to water and ammonia from the vessel. The latter is estimated and corrected for. By heating the closed vessel during the collection of the water considerable time can be saved. This can best be done by immersing the closed vessel in hot water, in the calorimeter.

It will be appreciated that direct determination of water is a somewhat laborious operation. The theoretical estimation of its equivalent to the "missing" oxygen and hydrogen has the merit of simplicity, and experience shows that the result is generally sufficiently accurate. The weakness in the method undoubtedly is due to the fact that some of the gases will undoubtedly be absorbed by the soot and steel dust cooling from high temperature in the closed vessel. Any serious errors in the estimation are however clearly shown by the degree of "heat balance" obtained at the end of the computation of the results.

PART III CALCULATION OF RESULTS

Introduction

Parts I and II of this report have outlined the experimental procedure to estimate the total heat and the products evolved on the detonation of a charge of high explosive in the closed vessel. In Part III the methods of interpreting these data and expressing them per gram of the main charge are illustrated by reference to results from four firings of common explosives. These are tetryl, picric acid, R.D.X./T.N.T. 50/50 and T.N.T. They were detonated in steel confining vessels of 1/4" wall thickness. For tetryl and picric acid the exploder pellets were made of the same explosive as the main charge and pressed to the same density. With R.D.X./T.N.T. and T.N.T. however, the exploder pellets were of a very low density. Satisfactory detonations were confirmed by examination of the steel fragments of the confining vessel. The detonators used to initiate the exploders were Commercial No. 8 A.S.A. The sheaths of these contain 0.88 grms. of aluminium and as only a small proportion of the sheath projected into the exploder pellets, the rest being encased by the detonator holder half the sheath is assumed to be oxidised to Al_2O_3, the rest remaining as aluminium.

The effects of the small amount of styphnate and azide are neglected, the explosive content of the detonator being taken as 0.5 grms. of tetryl.

A. The Analytical Result Sheet

The analytical result sheet (Tables 3, 5, 7, 9, appended) sets out in successive columns (a) the percentages of gases measured, (b) these percentages adjusted arbitrarily to total 100.00 and (c) the volumes of the individual gases contributing to the total measured volume at N.T.P. The column headed "Total Gaseous Products" gives the volumes both in litres corrected for minor products and those found in solution. Thus, "gases sol. in KOH" are corrected for HCN, C_2N_2 and NH_4HCO_3 and the result is expressed as carbon dioxide; carbon monoxide is adjusted for ammonia in the gases as the latter will have been absorbed with the CO in the gas analysis apparatus; ammonia is the total NH_4 radical in bicarbonate, cyanide, etc.

In the centre portion of the table the amounts of carbon, hydrogen, nitrogen and oxygen determined in the analysed products are subtracted from the ultimate molar composition of the original system which has been inserted at the foot of the table. The resulting untraced oxygen is first reduced by the amount required to combine with 0.44 g. of aluminium of form Al_2O_3 and the remainder is assumed to have formed water; likewise, the untraced hydrogen is assigned to water as explained in Part II. The carbon difference is taken to represent the amount of solid carbon (amorphous) which separates out in the reaction.

As a check on the overall experimental accuracy, the theoretical heat balance, calculated from the heats of formation of the reactants and products, is finally entered in the table and compared with the measured heat. The agreement is not exact, but the discrepancy should not normally exceed 2 per cent.

B. Calculation of the Heat and Gases of Detonation

1. Preliminary adjustments

Before being able to express the heat and gases in terms "per gm. of explosive" certain adjustments have to be made to the measured figures (These are set out in tables 4, 6, 8, 9 and 10) (a) for the initial atmosphere of nitrogen and for the minor products which are formed during the later stages of detonation and are affected by the conditions of firing

i.e., surface reactions on the steel walls of the closed vessel and (b) for the contribution made by the detonator itself. The exploder pellets are classed as part of the main charge and in consequence no corrections for them are applied. Whilst it is realised that the mode of detonation of the low density pellets will be different from the main charge, the magnitude of such differences will be small, when the results are expressed "per gram of charge" as the ratio of main charge to exploder is usually greater than six to one.

2. Minor Products

(a) A small correction is applied to the measured heat for the formation of ammonium compounds (in this case bicarbonate) from their constituent gases.

(b) The small amounts of methane and ammonia are reckoned as carbon, hydrogen and nitrogen and the products adjusted to be methane-free and ammonia-free and allowance made for their heats of formation. While it is possible that these two by-products are the result of secondary reactions involving some of the other gaseous products, it is unlikely that the true correction would differ from that based on the simple assumption of decomposition into their elements to such an extent as to affect the final result appreciably.

3. The detonator

As previously stated this is assumed to contain 0.5 grms. of tetryl. The heat and gases from this explosive are taken to be proportional by weight to those of the charges of tetryl illustrated in Tables 2 and 3.

0.44 grms of the aluminium detonator sheath are assumed to react with the water formed from the charge, aluminium oxide being produced, viz:

$$2\,Al + 3H_2O \rightarrow Al_2O_3 + 3H_2 + 3597 \text{ cals/grm Al as } Al_2O_3$$

The total heat and gases are adjusted accordingly for these effects of the detonator. The standard correction applied is given in full in Table 2.

4. Final evaluation of the results

In Tables 3, 5, 7 and 9 these corrections are applied in stages to the measured heat and gases, and the result reduced to unit weight of charge in order to facilitate comparison between different explosives. These results refer to standard temperature and pressure, water liquid. At 100°C and upwards, however, they are considerably modified when water is present in appreciable quantities and it is usual to express the results in an alternative form, i.e. water gaseous, by increasing the gases by the volume of the water vapour and diminishing the heat by the heat of vapourisation of the water.

Acknowledgements

Thanks are due to Dr. D. F. Runnicles and Mr. V. C. Broom for advice and assistance in the compilation of this Memorandum and acknowledgement is made of the work of Dr. T. C. Sutton and Dr. H. R. Ambler, late of this Establishment, who were responsible for the design of some of the equipment.

TABLE 2

Effect of Detonator Case and Contents on the Heat and Gases of a main charge.

CO_2	CO	H_2	N_2	C	H_2O	Total Gas	Total Heat	Remarks
mls	mls	mls	mls		mls	W.L. mls	W.L. cals	
119	297	86	187	130	99	689	1154	Abstracted from Table 4 i.e. Heat and Gases from 1 grm of Tetryl
60	148	43	93	65	49	344	577	Heat and gases from 0.50 grms Tetryl
		548			-548	548	1583	Effect on Products of 0.44 gms Aluminium in Detonator case Al_2O_3
60	148	591	93	65	-499	892	2160	Total effect of detonator and contents (tetryl)

TABLE 3

ANALYTICAL RESULT SHEET

Charge: 47.5 grms Tetryl (Density 1.50)
Exploder: 16.7 gms Tetryl (Density 1.50)
Detonator: No.8 ASA containing 0.50 grms Tetryl

Detonated in ¼" steel wall confinement

Analysis		Adjusted % Composition	Volumes mls.	Total Gaseous Products (inc. those in solution) mls.	
GAS Sol in KOH	13.29	13.30	7200	CO_2 7200-35+530	7695
CO	35.51	35.53	19240	CO 19240	19240
H_2	8.19	8.19	4435	H_2 4435	4435
CH_4	0.73	0.73	395	CH_4 395	395
N_2	42.23	42.25	22875	N_2 22875	22875
NH_3 35			35	NH_3 35+530	565
HCN 35				HCN 35	35
C_2N_2				C_2N_2	
TOTAL	99.95	100.00	54180		55240
SOLUTION Am. Bicarb 530			= Total Gas Volume		
Am. Cyanide					
C_2N_2					

C	H_2 mls.	N_2 mls.	O_2 mls.
7695	4435	22875	7695
19240	790	285	9620
395	850	15	
35	15		
27365	6090	23175	17315
35335	12615	23705	20185
7970	6525	530	2870
	as H_2O of 5192		to Al_2O_3 274
	Mean 5858 Mls H_2O		2596 = 5192 mls. H_2O

Calculated heat	Cals (-)	Cals (+)
CO_2 4.2165x7695		32446
CO 1.1982x19240		23053
CH_4 0.8143x395		322
NH_3 0.4911x565		277
HCN -1.3705x35	48	
C_2N_2		
Am. Bicarb. 0.9991x530		530
Am. Cyanide		
H_2O 3.0522x5858		17880
Al_2O_3 7389x0.44		3251
Al_2O_3		
ALN		
C Diamond to Amorphous - 0.0781x7970	622	
H.F. Tetryl 25.85x647		1672
	670	79431
Balance		78761

cf. Measured Heat 77,300 cals

Ultimate Composition mls.

CHARGE		C	H_2	N_2	O_2
47.5 gms) 16.7 ") 0.50 ")	64.7 gms Tetryl	35333	12617	12617 *11090 23707	20187

Aluminium Detonator Sheath = 0.88 gms. Al of which 0.44 gms. Al_2O_3

*N_2 in vessel Initially.

TABLE 4

Heats of Detonation and Product Gases of Tetryl
(Charge Wt. 64.7 grms.)

Products of Detonation (mls)									Total Gas		Total Heat		Remarks
Measured Products						Estimated Products			Water Liquid	Water gaseous	Water liquid	Water gaseous	
CO_2	CO	H_2	CH_4	N_2	NH3/HCN	C	H_2O	Al as Al_2O_3 grms	mls	mls	cals	cals	
7695	19240	4435	395	22875	565/35	7970	5858	0.44	55240	-	77300	-	Extracted from Analytical Result Sheet Table No.3
7695	19240	6090	-	12085	-	8400	5858	0.44	45110	-	76219	-	After simplification by adjusting for minor product formation and initial nitrogen
7695	19240	5542	-	12085	-	8400	6406	-	44562	50968	74636	71612	After further adjustment due to correction for aluminium detonator sheath and contents
119	297	86	-	187	-	130	99	-	689	788	1154	1107	Heat and Gases from 1 gm of tetryl

TABLE 5

ANALYTICAL RESULT SHEET

Charge: 80 grms Picric Acid (Density 1.70)
Exploder: 19 grms Picric Acid (Density 1.50)
Detonator: No. 8 ASA containing 0.50 grms Tetryl

Detonated in ¼" steel wall confinement

Analysis		Adjusted % Composition	Volumes mls	Total Gaseous Products (inc. those in solution)	mls
GAS Sol in KOH	23.59	23.57	16795	CO_2 16795+655	17450
CO	33.63	33.60	23940	CO 23940	23940
H_2	7.11	7.10	5060	H_2 5060	5060
CH_4	0.31	0.31	220	CH_4 220	220
N_2	35.45	35.42	25235	N_2 25235	25235
NH_3 25 mls			25	NH_3 25+655	680
HCN				HCN	NIL
C_2N_2				C_2N_2	NIL
	100.09	100.00	71275		72585
SOLUTION Am. Bicarb 655 mls			= Total Gas Volume		
Am. Cyanide NIL					
C_2N_2 NIL					

C	H_2 mls	N_2 mls	O_2 mls
17450	5060	25235	17450
23940	440	340	11970
220	1020		
41610	6520	25575	29420
58345	14620	26710	34035
16735	8100	1135	4615
= Missing Carbon as soot	as H_2O cf 8682		to Al_2O_3 274
	Mean H_2O 8391		4341
			≡ 8682 ml. of H_2O

Ultimate Composition mls

CHARGE		C	H_2	N_2	O_2
80 gms) 19 gms)	99 gms Picric Acid	58073	14523	14523	33878
0.50 gms Tetryl		273	98	98	156
TOTAL		58346	14621	14621	34034
				*12089	
				26710	

Aluminium Detonator Sheath
= 0.88 gms of which 0.44 gms Al_2O_3
* N_2 in vessel Initially

Calculated Heat	Cals (-)	Cals (+)
CO_2 4.2165x17450		73578
CO 1.1982x23940		28685
CH_4 0.8143x220		179
NH_3 0.4911x680		334
HCN		
C_2N_2		
Am. Bicarb 0.9991x655		654
Am. Cyanide		
H_2O 3.0522x8391		25611
Al_2O_3 0.44x7389		3251
Al_2O_3		
AlN		
C Diamond		
Amorphous 0.0781x16735	1307	
H.F. Picric Acid 215.07x99	21291	
H.F. Tetryl -25.85x0.50		13
	22598	132305
Balance		109707
Measured Heat cf		109700

TABLE 6

Heat of Detonation and Product Gases of Picric Acid
(Charge Wt. 99 grms.)

Products of Detonation									Total Gas		Total Heat		Remarks
Measured Products						Estimated Products			Water liquid	Water gaseous	Water liquid	Water gaseous	
CO_2	CO	H_2	CH_4	N_2	NH3/HCN	C	H_2O	grms. Al as Al_2O_3	mls	mls	cals	cals	
17450	23940	5060	220	25235	680/ -	16735	8391	0.44	72585	-	109700	-	Extracted from Analytical Result Sheet Table No.5
17450	23940	6520	-	13486	-	16955	8391	0.44	61396	-	108533	-	After simplification by adjusting for minor product formation and initial nitrogen
17390	23792	5929	-	13393	-	16390	8890	-	60504	69394	106373	102179	After further adjustment due to correction for aluminium detonator sheath and contents
176	240	60	-	135	-	173	90	-	611	701	1074	1032	Heat and Gases from 1 gm of Picric Acid

TABLE 7

ANALYTICAL RESULT SHEET

Main Charge: 97.81 gms T.N.T. (density 1.58)
Exploder: 16.7 gms T.N.T. (density 1.35)
Detonator: No. 8 A.S.A. containing 0.50 gms Tetryl

Detonated in ¼" steel wall confinement

Analysis		Adjusted % Composition	Volumes mls	Total Gaseous Products (inc. those in solution)	mls
GAS Sol in KOH	15.78	15.81	12,130	CO_2 12130+1110-70	13170
CO	35.49	35.56	27,280	CO 27280	27280
H_2	12.11	12.13	9,305	H_2 9305	9305
CH_4	1.06	1.06	815	CH_4 815	815
N_2	35.38	35.44	27,190	N_2 27190	27190
NH_3 45			45	NH_3 45+1110	1155
HCN 70				HCN 70	70
C_2N_2				C_2N_2	
	99.82	100.00	76,765		78985
SOLUTION Am. Bicarb 1110			= Total Gas Volume		
Am. Cyanide					
C_2N_2					

C mls	H_2 mls	N_2 mls	O_2 mls
13170	9305	27190	13170
27280	1630	580	13640
815	1735	35	
70	35		
41335	12705	27805	26810
79320	28335	29045	34040
37985	15630	1240	7230
as soot	as H_2O		to Al_2O_3 274
	of 13912		6956
	14771		= 13912
	Mean H_2O		mls. H_2O

Calculated Heat	Cals (-)	Cals (+)
CO_2 4.2165x13170		55531
CO 1.1982x27280		32687
CH_4 0.8143x815		664
NH_3 0.4911x115		567
HCN -1.3705x70	96	
C_2N_2		
Am. Bicarb 0.9991x1110		1109
H_2O 3.0522x14771		45084
Al_2O_3 7389x0.44		3251
Al_2O_3		
ALN		
C Diamond		
Amorphous 0.0781x37985	2967	
H.F. T.N.T. 68.15x114.51	7804	
H.F. Tetryl -25.85x0.50		13
	10867	138906
Balance		128039
of measured heat		127,270

Ultimate Composition mls

CHARGE	C	H_2	N_2	O_2
97.81 gms T.N.T.	67518	24130	14466	28942
16.70 gms T.N.T.	11528	4118	2470	4942
0.50 gms Tetryl	273	98	98	156
	79319	28336	17034	34040
			*12012	
			29046	

Aluminium Detonator Sheath
= 0.88 gms Al of which
0.44 gms Al_2O_3

* Initial Nitrogen

TABLE 8

Heat of Detonation and Product Gases of T.N.T.
(Charge Wt. 114.51 grms.)

Products of Detonation (mls)									Total Gas		Heat		Remarks
Measured Products						Estimated Products			Water liquid	Water gaseous	Water liquid	Water gaseous	
CO_2	CO	H_2	CH_4	N_2	NH3/HCN	C	H_2O	grms. Al as Al_2O_3	mls	mls	cals	cals	
13170	27280	9305	815	27190	1155/70	37985	14771	0.44	78985	-	127270	-	Extracted from Analytical Result Sheet Table 7
13170	27280	12703	-	15790	-	38870	14771	0.44	68943	-	125026	-	After simplification by adjusting for minor product formation and initial nitrogen
13110	27132	12112	-	15697	-	38805	15270	-	68051	83321	122866	115898	After further adjustment due to correction for aluminium detonator sheath and contents
114	237	106	-	137	-	339	133	-	594	727	1074	1013	Heat and Gases from 1 grm of T.N.T.

TABLE 9

ANALYTICAL RESULT SHEET

ain Charge: 99 gms R.D.X./T.N.T. 50.15/49.85(density 1.68) Detonated in $\frac{1}{4}$" steel wall confinement
.ploder: 16.7 grms RDX/TNT 50/50 (density 1.40)
etonator: No.8 A.S.A. containing 0.50 gms Tetryl

Analysis		Adjusted % Composition	Volumes mls.	Total Gaseous Products (inc. those in solution)	mls.
AS Sol in KOH	14.39	14.39	12080	CO_2 12080-75+1465	13470
CO	28.94	28.94	24290	CO 24290	24290
H_2	11.68	11.68	9805	H_2 9805	9805
CH_4	0.66	0.66	555	CH_4 555	555
N_2	44.35	44.33	37210	N_2 37210	37210
NH_3 55			55	NH_3 55+1465	1520
HCN 85				HCN 85	85
C_2N_2				C_2N_2	
TOTAL	100.00	100.00	83995		86935
SOLUTION Am. Bicarb 1465			= Total Gas Volume		
Am. Cyanide					
C_2N_2					

C mls	H_2 mls	N_2 mls	O_2 mls
13470	9805	37210	13470
24290	1110	760	12145
555	2280	45	
85	45		
38400	13240	38015	25615
57648	31872	38706	34775
19248	18632	691	9160
as soot	as H_2O		to Al_2O_3 274
	cf 17772		8886
	Mean H_2O 18157 mls.		= 17772 mls. H_2O

Calculated Heat	Cals (-)	Cals (+)
CO_2 4.2165x13470		56796
CO 1.1982x24290		29104
CH_4 0.8143x555		452
NH_3 0.4911 x 1520		746
HCN 1.3705x85	116	
C_2N_2		
Am. Bicarb 0.9991x1465		1464
Am. Cyanide		
H_2O 3.0522x18157		55419
Al_2O_3 7389x0.44		3251
Al_2O_3		
ALN		
C Diamond		
Amorphous -0.0781x19248	1503	
H.F.R.D. -38.02x58.0		5105
H.F. T.N.T. 68.15x57.70	3932	
H.F. Tetryl -25.85x0.50		13
	5551	152350
Balance		146799 cals

of Measured Heat 147540 cals

Ultimate Composition mls

CHARGE	C	H_2	N_2	O_2
58.00 gms RDX	17545	17545	17545	17545
57.70 gms TNT	39830	14229	8534	17074
0.50 Tetryl	273	98	98	156
	57648	31872	26177	34775
			* 12529	
			38706	

Aluminium Detonator Sheath
0.88 gms Al of which
0.44 gms Al_2O_3

* Initial Nitrogen

TABLE 10

Heat of Detonation and Product Gases of RDX/TNT 50/50
(Charge Wt. 115.7 grms.)

Products of Detonation (mls)									Total Gas		Heat		Remarks
Measured Products						Estimated Products			Water liquid	Water gaseous	Water liquid	Water gaseous	
CO_2	CO	H_2	CH_4	N_2	NH3/HCN	C	H_2O	grms Al as Al_2O_3	mls	mls	cals	cals	
13470	24290	9805	555	37210	1520/85	19248	18157	0.44	86935	-	147540	-	Extracted from Analytical Result Sheet Table 9
13470	24290	13238	-	25483	-	19888	18157	0.44	76481	-	144944	-	After simplification by adjusting for minor product formation and initial Nitrogen
134100	24142	12647		25390	-	19823	18656	-	75589	94245	142837	134036	After further adjustment due to correction for aluminium detonator sheath and contents
116	208	109	-	220	-	171	161	-	653	814	1234	1158	Heat and Gases from 1 gm RDX/TNT 50/50

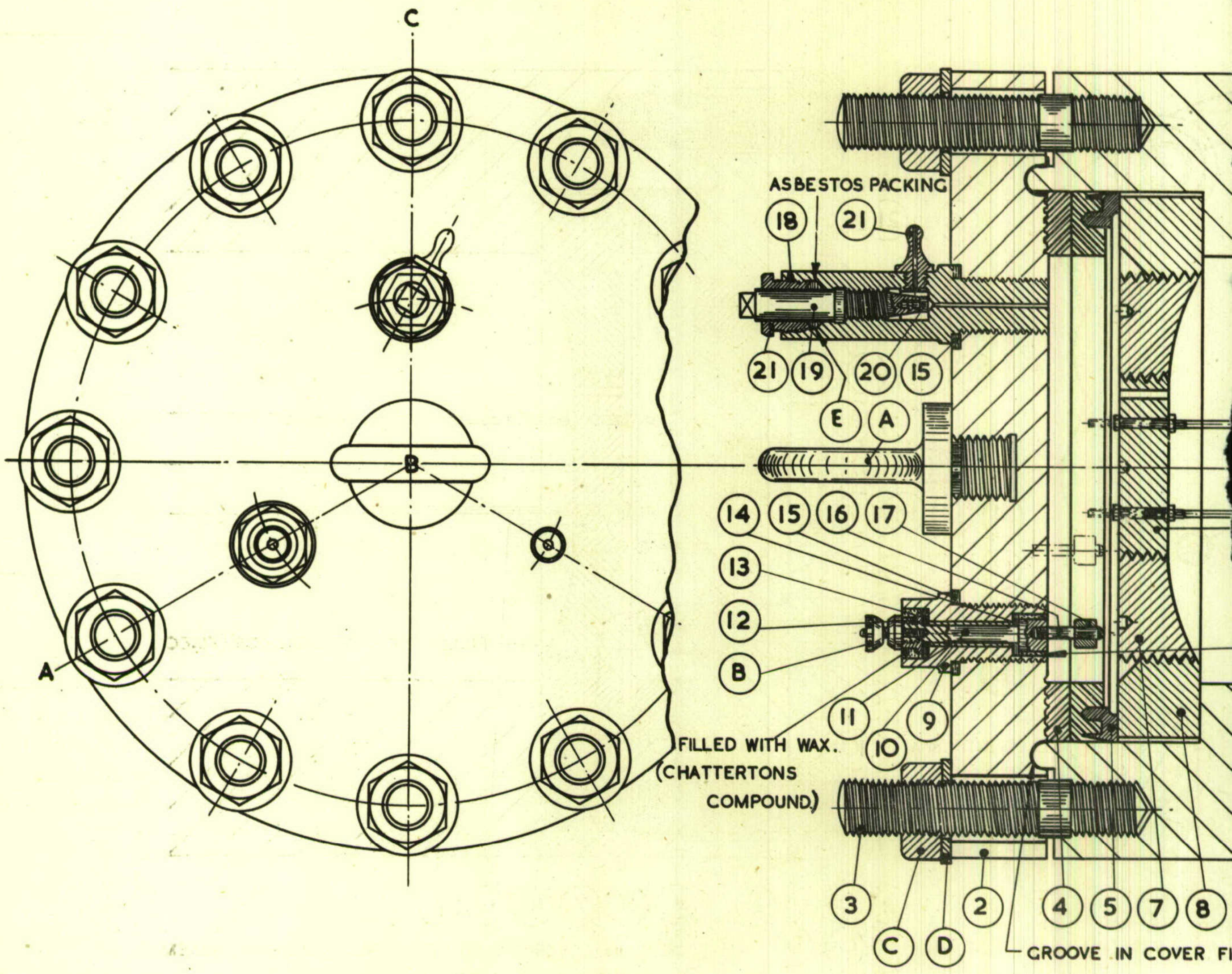
TABLE 11

Heats of Formation

Substance	Mol. wt. grms.	Heat of Formation K cals/mol.	Heat of Formation cals/mol.	Source
Carbon (Diamond)	12.0	0	0	
Carbon (Amorphous)	12.0	-1.75	-0.0781	Bichowsky
CO_2	44.01	94.45	4.2165	and
CO	28.01	26.84	1.1982	Rossini
CH_4	16.03	18.24	0.8143	Thermo-Chem.
H_2O (liq.)	18.02	68.37	3.0522	of
H_2O (gas)	18.02	57.80	2.5804	Chem. Subs.
HCN (gas)	27.02	-30.70	-1.3705	(the carbon
C_2N_2(gas)	52.02	-71.0	-3.1696	amorphous figure
NH_3 (gas)	17.03	11.0	0.4911	is a mean of
NH_4HCO_3 (NH_3.H_2O.CO_2) (g) (liq.) (g)	79.05	22.38	0.9991	different forms

Explosive	mol. wt.	Formulae	Heat of combustion K cals/mol	Heat of Formation K cals/mol.	Heat of Formation cals/gm.
Tetryl	287	$C_7H_5O_8N_5$	839.5	-7.42	-25.85
R.D.X.	222	$C_3H_6O_6N_6$	508.0	-19.54	-88.02
T.N.T.	227	$C_7H_5O_6N_3$	816.6	+15.47	+68.15
Picric Acid	229	$C_6H_3O_7N_3$	620.0	+49.25	215.07

1



SUMMARY OF PARTS.			
ITEM No.	SHEET No.	DESCRIPTION	MATERIAL
1	10	EXPLOSION VESSEL BODY	STEEL
2	10	EXPLOSION VESSEL COVER	STEEL
3	10	STUD	STEEL
4	10	WASHER	LEAD
5	10	KNIFE RING	STEEL
6	10	BAFFLE PLATE PLUG	STEEL
7	11	INNER BAFFLE PLATE	STEEL
8	11	OUTER BAFFLE PLATE	STEEL
9	11	ELECTRODE BODY	STEEL
10	11	ELECTRODE STEM	STEEL
11	11	ELECTRODE INSULATING BUSH	EBONITE
12	11	ELECTRODE NUT	STEEL

SUMMARY OF PARTS CONT		
ITEM	SHEET	DESCRIPTION
13	11	ELECTRODE WASHER, LARGE
14	11	ELECTRODE WASHER, SMALL
15	11	WASHER
16	11	PIN
17	11	COLLAR
18	11	VALVE BODY
19	11	VALVE SPINDLE
20	11	VALVE
21	11	VALVE GLAND
22	11	VALVE NOZZLE
23	11	CONFINING VESSEL.

FIG. 1. H.E. BOMB CALORIMETE

ASSEMBLY OF H.E. EXPLOSION VESS

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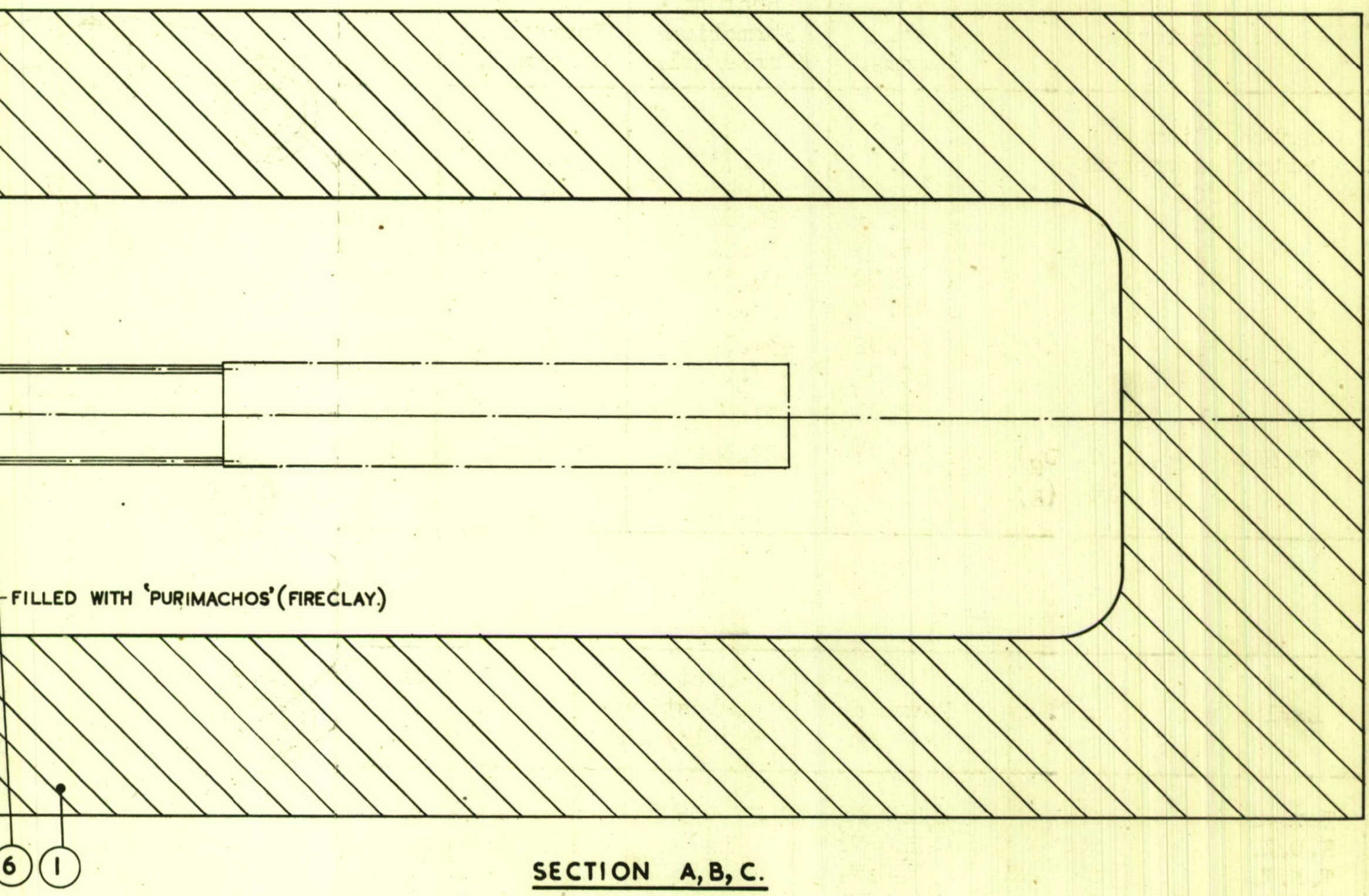

SECTION A, B, C.

LLED WITH SOLDER BEFORE ASSEMBLY.

NUED.
MATERIAL
TUFNOL
TUFNOL
COPPER
STEEL
STEEL
STEEL
STEEL
STEEL
STEEL
STEEL
STEEL

STANDARD PARTS REQUIRED PER. ASSEMBLY			
LETTER	DESCRIPTION	LENGTH	MATERIAL
A	1" DIA. B.S.F. EYE BOLT		STEEL
B	No. 4 B.A. TERMINALS		BRASS
C	$\frac{7}{8}$" DIA. B.S.F. NUT		STEEL
D	$\frac{7}{8}$" DIA. WASHER		STEEL
E	PACKING		ASBESTOS

R SYSTEM.

EL (CLOSED)

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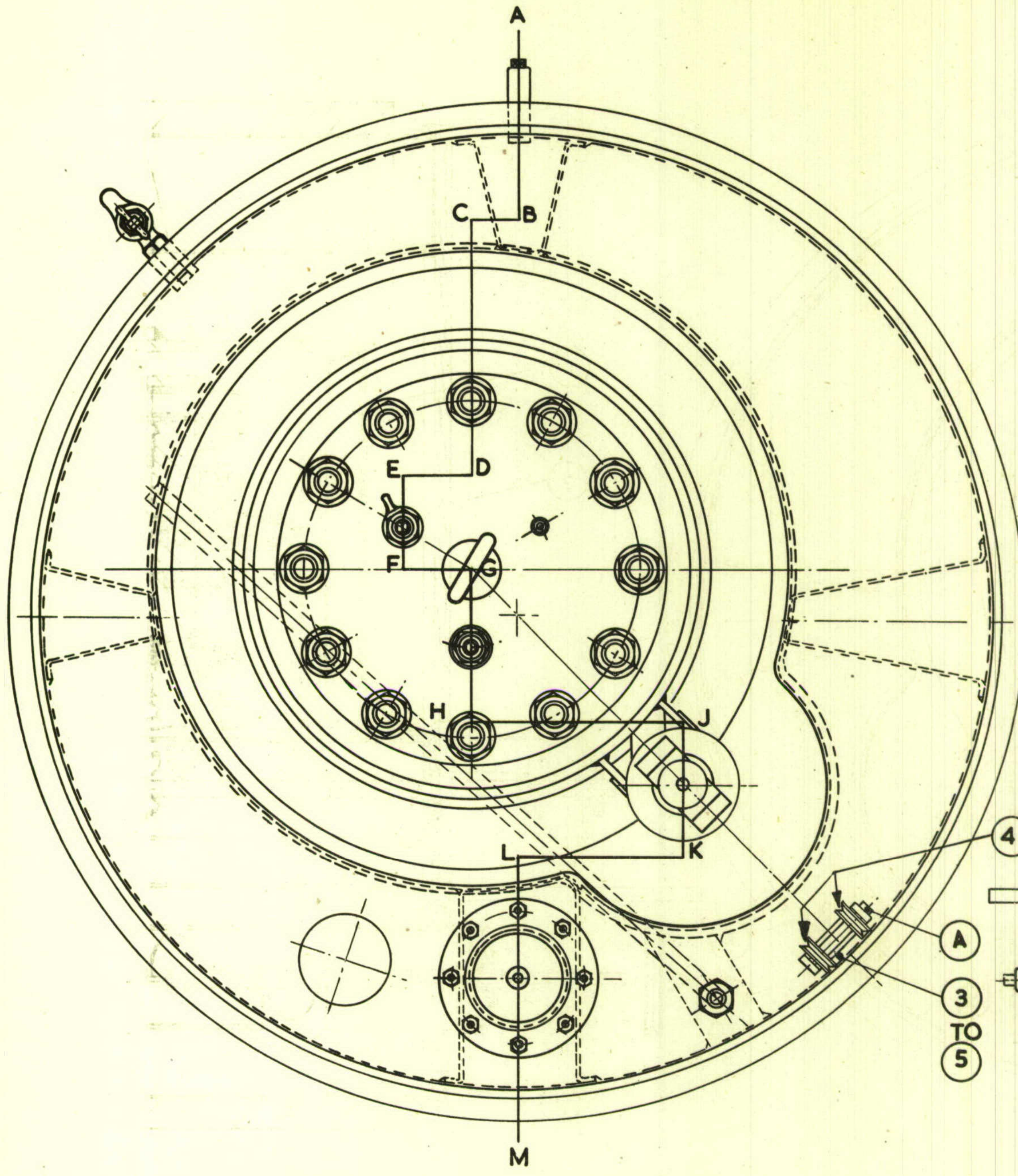

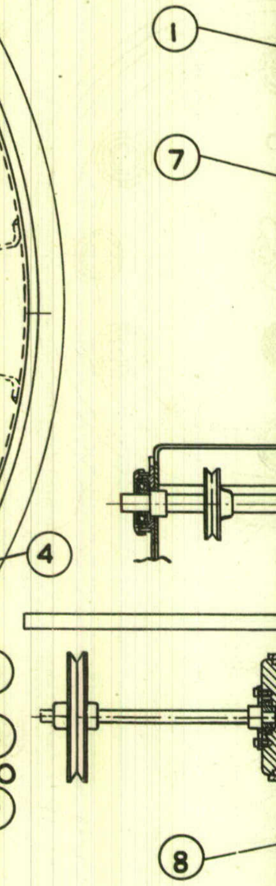

PLAN WITH COVERS REMOVED.

SUMMARY OF PARTS.		
ITEM No.	DESCRIPTION	MATERIAL
1	TANK LID	COPPER
2	ASSEMBLY OF WATER JACKET	
3	BRACKET	BRASS
4	PULLEY	BRASS
5	SLEEVE	M.S.
6	TANK STAND	TUFNOL

SUMMARY OF PARTS CONTINUED.		
ITEM No.	DESCRIPTION	MAT
7	COVER	WOO BR
8	ASSEMBLY OF WATER STIRRER	
9	ASSEMBLY OF EXPLOSION VESSEL.	
10	EXPLOSION VESSEL STAND.	WOO
11	CALORIMETER	STE

FIG. 2 H.E. BOMB CALORI

2

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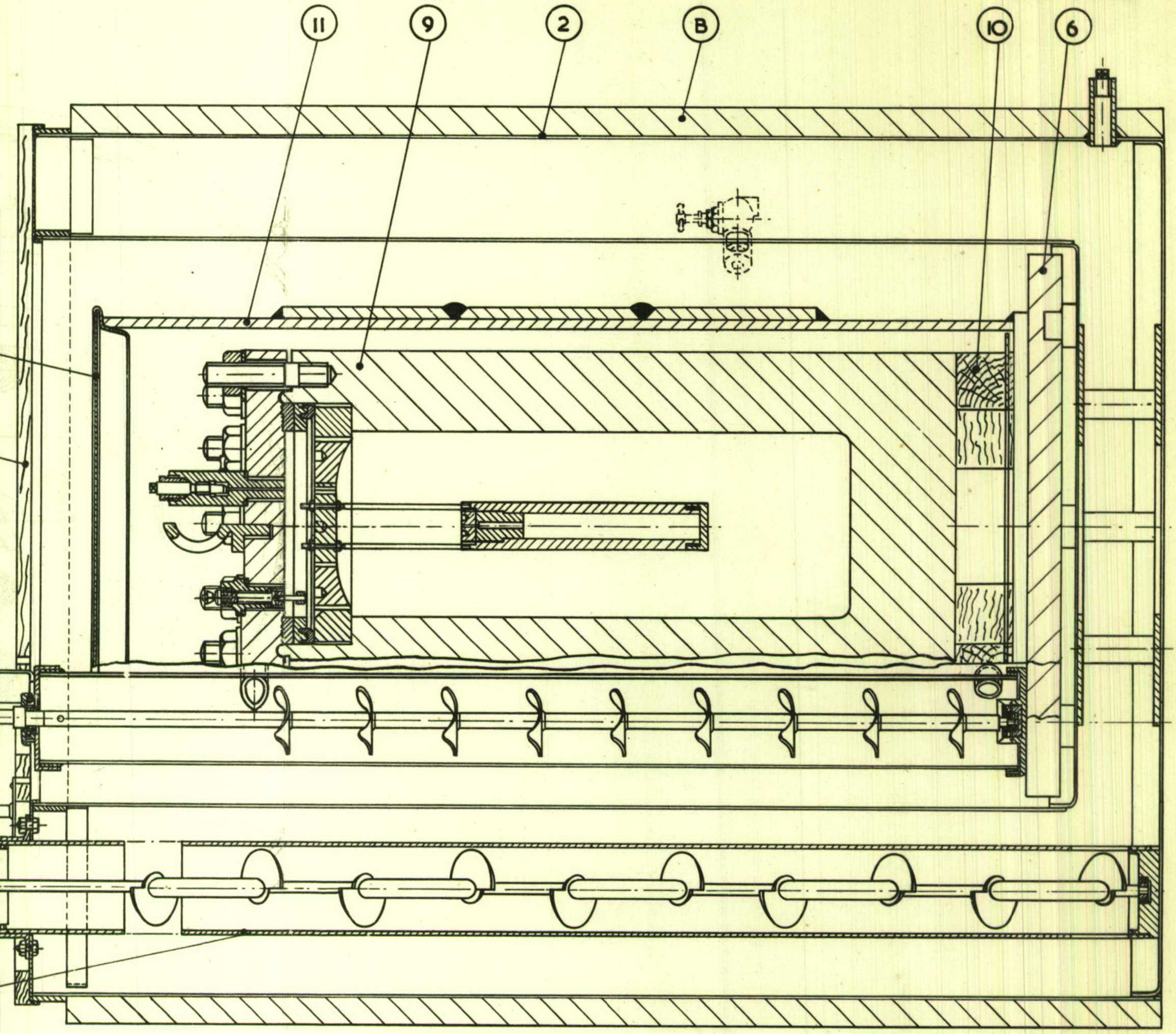

SECTION THROUGH A-M

STANDARD PARTS REQUIRED PER. ASSEMBLY.					
LETTER	DESCRIPTION	LENGTH	MATERIAL	No.OFF	REMARKS
A	$\frac{3''}{16}$ DIA. B.S.F. SOCKET SHOULDER SCREW	$2\frac{3''}{8}$	STEEL	1	DIA. PLAIN PORTION $\frac{1''}{4}$
B	1" THICK FELT JACKET		FELT	1	$38\frac{3''}{4}$ X 68"

RIAL
D &
SS.

&M.S.
L

METER SYSTEM.

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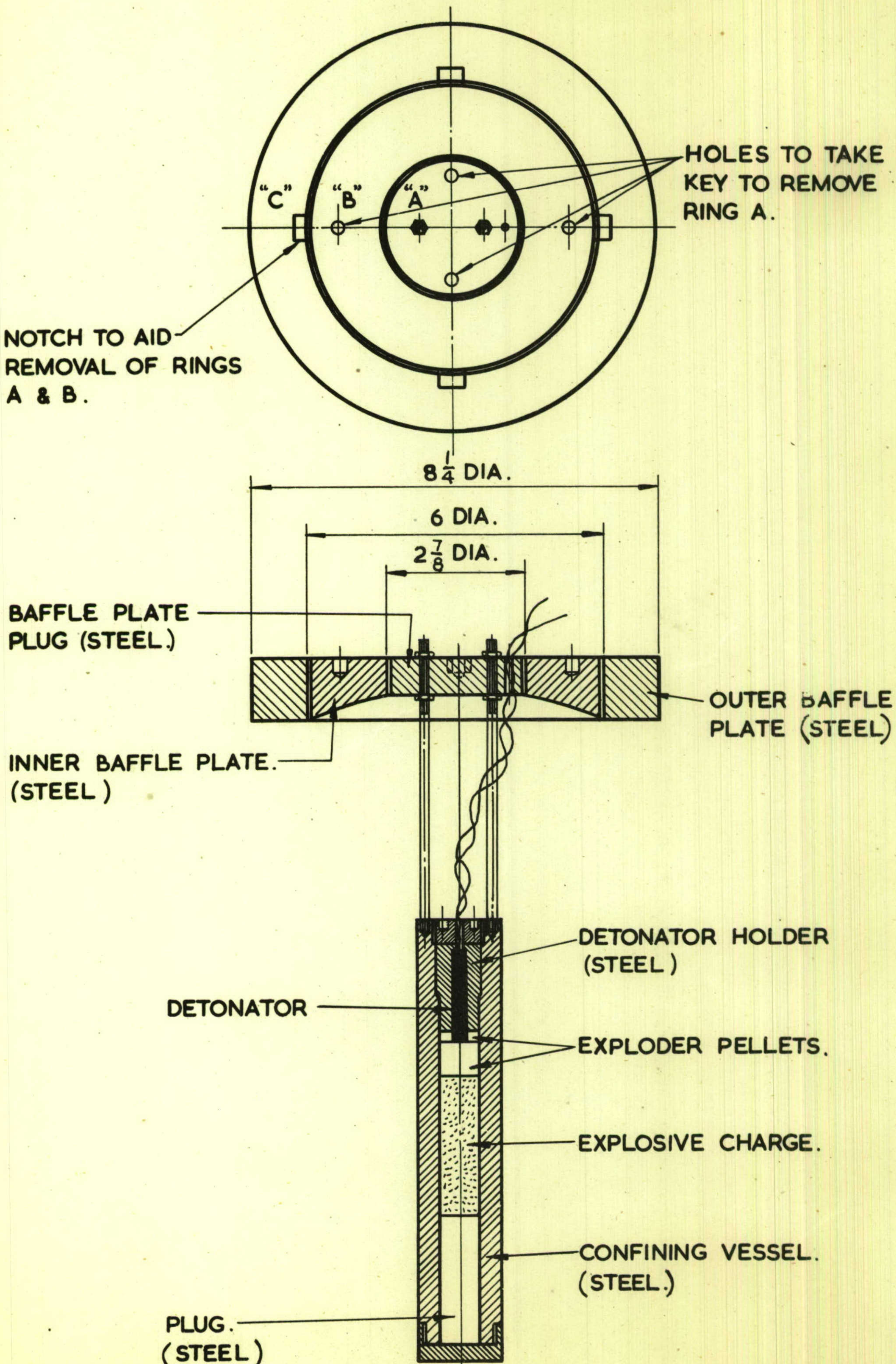


FIG. 3 CONFINING VESSEL & BAFFLE PLATE ASSEMBLY FOR H.E. VESSEL.

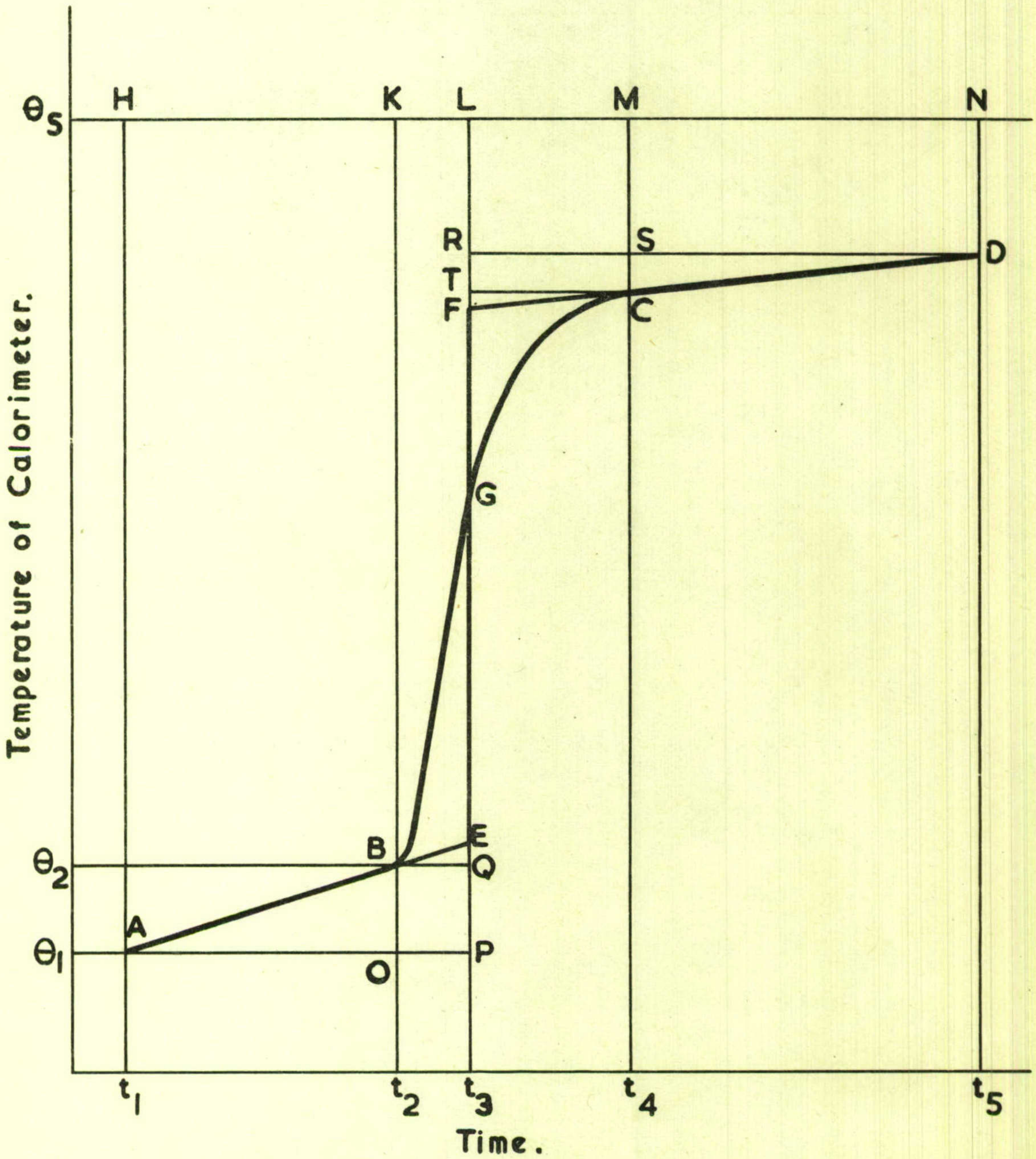
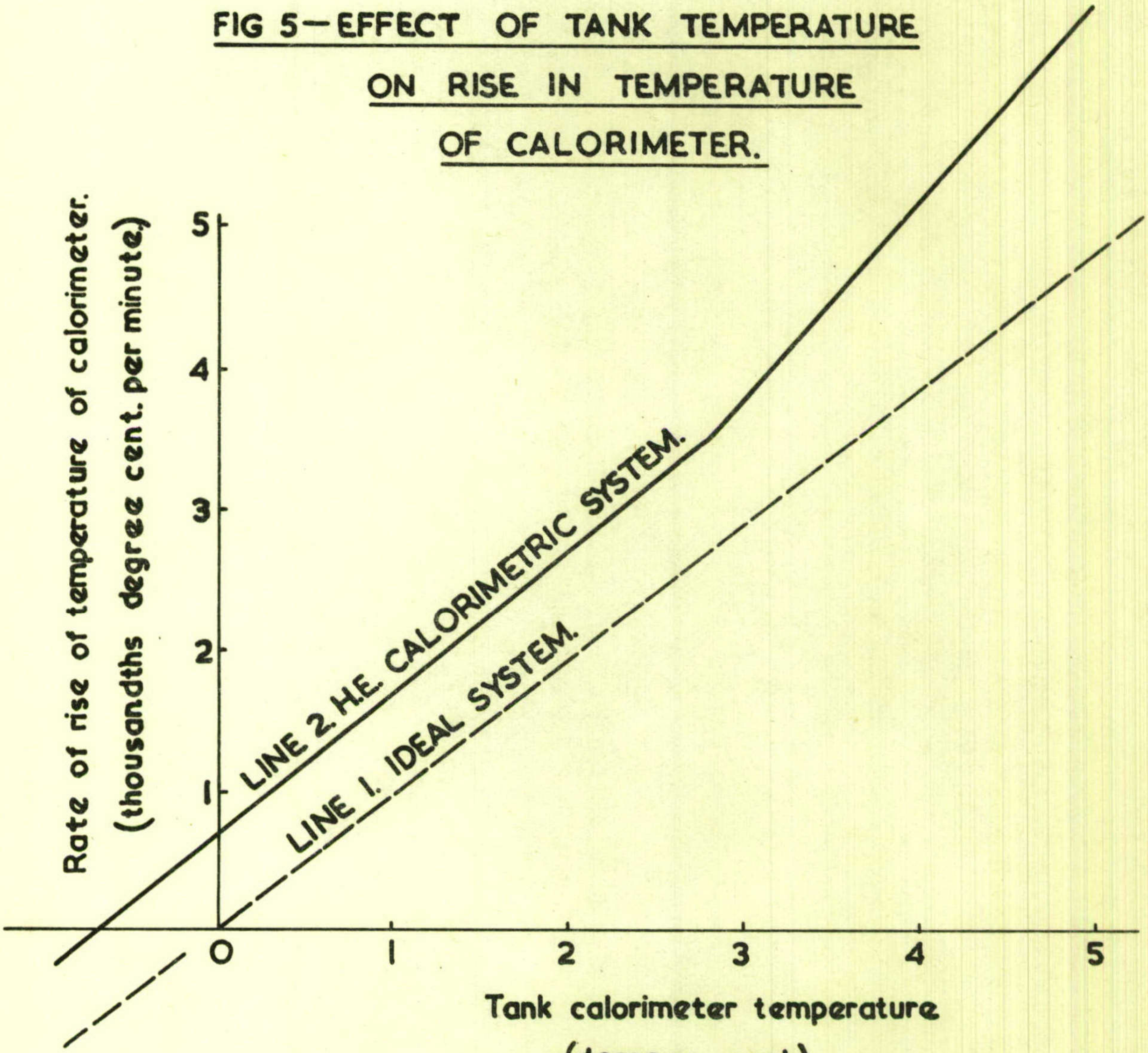


FIG.4 COMPUTATION OF TEMPERATURE RISE FOR CALORIMETRIC BOMB SYSTEMS.

FIG 5—EFFECT OF TANK TEMPERATURE ON RISE IN TEMPERATURE OF CALORIMETER.



Note Line 2 is based on experimental results.
Line 1 is purely illustrative.

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Armament Research & Development Establishment — 662.216.4:
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The method is illustrated by results from the firings of four common explosives, i.e. Tetryl, Picric Acid, RDX/TNT 50/50 and TNT.
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